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Autor: Fryba, Ladislav / Pirner, Miros
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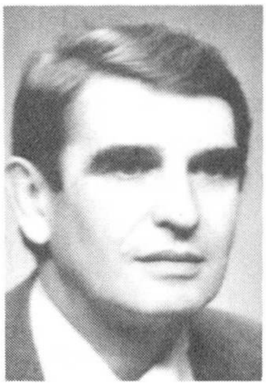
Monitoring and Evaluation of Bridges

Surveillance et évaluation des ponts

Überwachung und Beurteilung von Brücken

Ladislav FRYBA
Professor
Inst. of Theoretical & Applied Mech.
Prague, Czech Republic

Miros PIRNER
Professor
Inst. of Theoretical & Applied Mech.
Prague, Czech Republic



Ladislav Fryba, born 1929, studied civil engineering at the Technical University Prague. He is involved in the research of bridges and President of the Czech Society for Mechanics. Since 1984 he is at the Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences.

Miros Pirner, born 1928, received his civil engineering degree from Technical University Prague 1952. He has worked as assistant professor and as researcher. Since 1990 he is director of the Institute of Theoretical and Applied Mechanics of Czech Academy of Sciences.

SUMMARY

Monitoring of stresses provides the stress spectra, i.e. number and distribution of stress cycles in steel bridges subjected to traffic loads. Identification together with modal analysis after dynamic tests recognises the deterioration of the state of bridges as reflected in diminishing of natural frequencies and in deformations of modes of natural vibrations.

RÉSUMÉ

L'enregistrement des contraintes fournit les spectres des contraintes, c'est-à-dire le nombre et la distribution des cycles de contraintes dans les ponts métalliques sous charges de trafic. L'identification et l'analyse modale après les essais dynamiques reconnaissent les dommages aux ponts, qui se manifestent par une diminution des fréquences propres et des déformations des modes de vibration naturelle.

ZUSAMMENFASSUNG

Die Überwachung der Spannungen ergibt ein Spannungsspektrum, d.h. die Anzahl und die Verteilung der Spannungen in den Stahlbrücken unter Verkehrslasten. Die Identifikation und modale Analyse nach den dynamischen Versuchen lassen die Brückenbeschädigungen erkennen, welche sich durch die Verkleinerung der Eigenfrequenzen und der Deformationen der Eigenschwingungsformen ausdrücken.

1. INTRODUCTION

Monitoring is a process where some characteristics of the structure (deflections, strains, stresses, etc.) are recorded during a certain time (hours, days, months, years, etc.). On the other hand, identification is a process where the real properties of the structure are discovered from the response of the structure.

Several methods have been developped for both processes mentioned above and some of them, that were applied to bridges, will be referred in the present paper.

2. MONITORING OF STRESSES

Most of railway and highway bridges are subjected to irregular traffic loads that are more or less of the random character and they may be idealized by a stochastic process randomly variable in space and time. As the life of bridges is long (80 to 120 years) the knowledge of the current and expected strengths in bridges is very important for the estimation of their life, fatigue, maintenance, inspection intervals etc.

Therefore, the stresses were recorded in 5 railway and 3 highway bridges and the obtained stress-time records were evaluated using the rain-flow counting method [1]. The method supposes that the fatigue of steel structures depends first of all on the stress ranges (two stress ranges = one stress cycle), [2] :

$$\Delta\sigma = \sigma_{max} - \sigma_{min} \tag{1}$$

where σ_{max} or σ_{min} is a local maximum or minimum, respectively.

In such a way, the stochastic stress-time records are transformed into simple stress ranges and/or stress cycles. The rain-flow method supposes that the fatigue damage due to small stress ranges may be added to the fatigue damage due to big stress ranges without respect to their time sequence.

The result of counting is a histogram of frequency of stress ranges which is called stress spectrum. An example is shown in the Fig. 1. The stress spectra possess the following properties (for details see [3]) :

- both static and dynamic components of the response of bridges are included,
- a great number of cycles of small stress ranges appears (dynamic components) while the great stress ranges are rare (static components),
- the stress spectra depend on the intensity and composition of traffic loads,
- they depend on the shape and on the length of influence line of the investigated bridge element,
- they do not depend on any hypothesis of fatigue damage nor on Wöhler curve,
- the spectra possess large dispersions.

The statistical evaluation of results and the regression analysis provided an empirical formula for the number n_i of stress ranges in the i-th class per year :

$$n_i = aT^b L^c \lambda_i^d e^{ks} \tag{2}$$

where the following designation has been used :

T – number of heavy vehicles per 24 hours (devided by 500) for highway bridges, or
– mass of all trains on the given line per year for railway bridges (in million of tons),

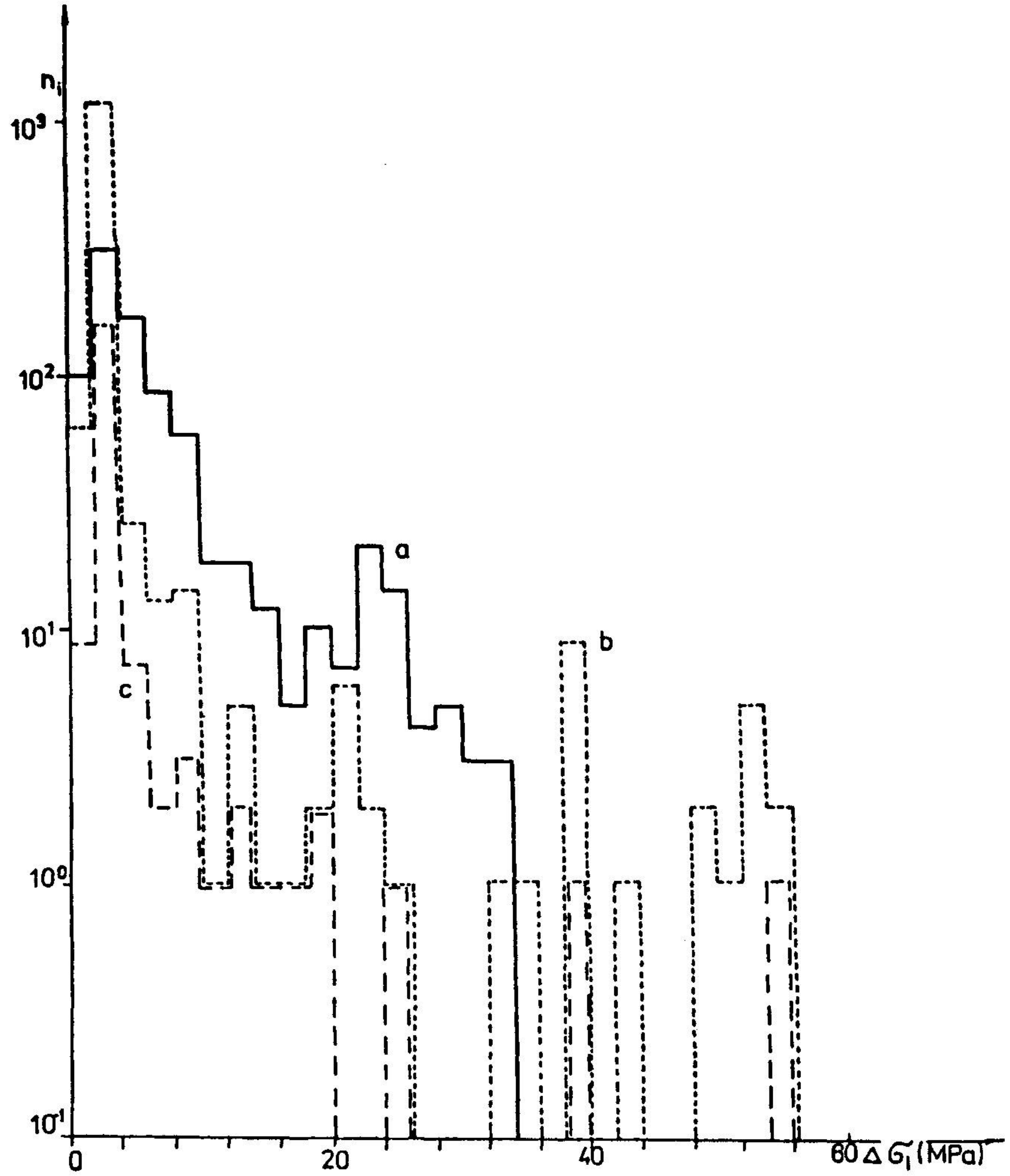


Fig. 1 Stress spectrum in the main girder of a steel railway bridge, L = 30 m
a) daily traffic, 65 trains,
b) 10 runs of a very heavy train,
c) one run of a very heavy train

L – length of influence line of the investigated element (in metres),

$\lambda_i = \Delta\sigma_i/\Delta\sigma_s = 0,1; 0,2; ...; 0,9; 1$ – dimensionless stress ranges, $\Delta\sigma_s$ – greatest stress range in the investigated bridge element due to standard life load multiplied by the standard dynamic impact factor,

a, b, c, d – regression coefficients (3) and (4),

s – standard deviation of measured data,

$k = 1,65$ – coefficient ascertaining the 95% reliability.

The experiments [3] have brought the following data :
for highway bridges :

$$\begin{array}{llllll} a = & 13,099 & b = & 1 & c = & -0,461 \\ d = & -5,208 & s = & 0,930 & k = & 1,65 \end{array} \tag{3}$$

for railway bridges :

$$\begin{array}{llllll} a = & 17,742 & b = & 0,860 & c = & -0,354 \\ d = & -4,464 & s = & 1,323 & k = & 1,65 \end{array} \tag{4}$$

The obtained statistical data have been applied to the design of bridges for fatigue and to the estimation of inspection intervals, see [3].

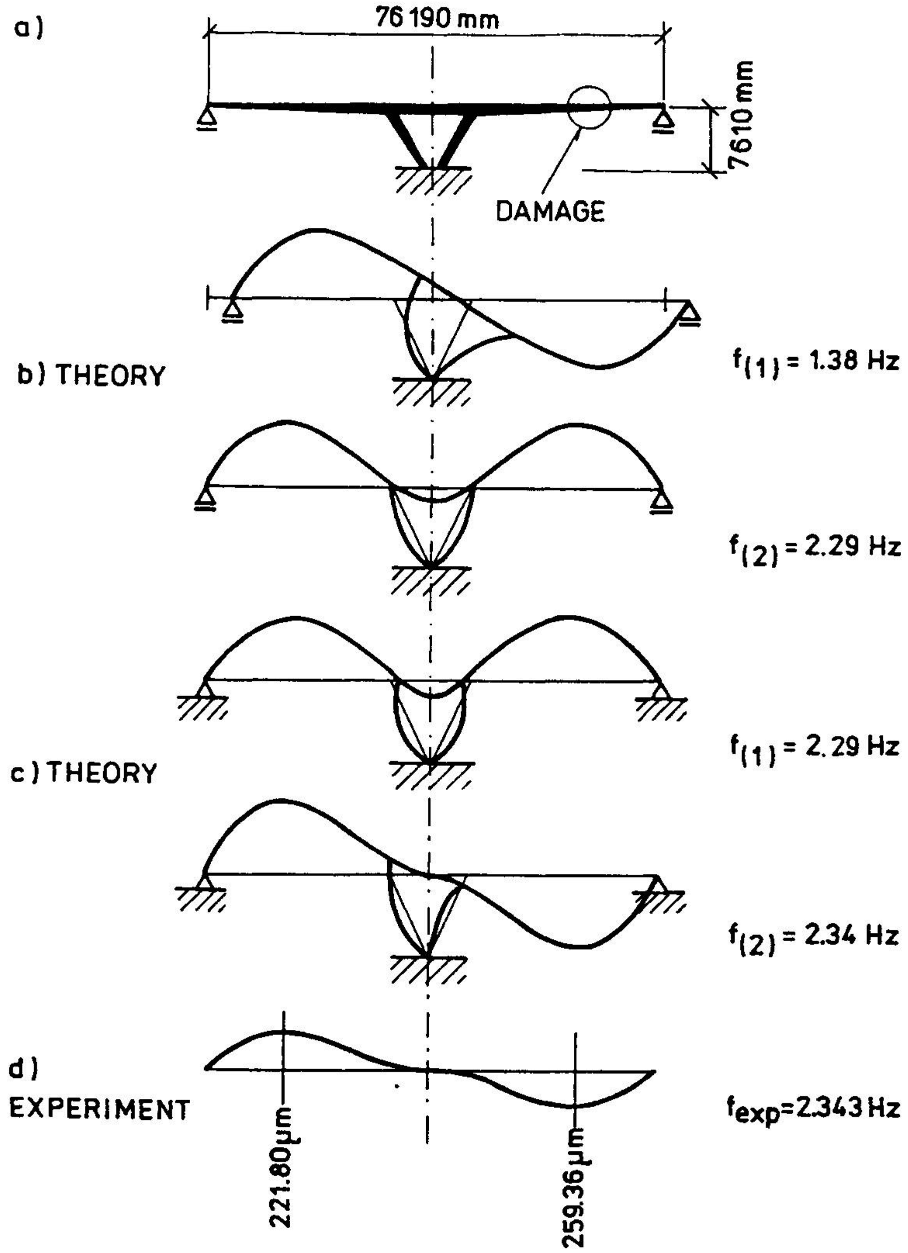


Fig. 2 Prestressed concrete highway bridge of length 76,19 m
a) scheme of the bridge,
b) theoretical modes of natural vibration of the bridge with moving bearings,
c) theoretical modes of natural vibration of the bridge with blocked bearings,
d) experimental mode of natural vibration

3. IDENTIFICATION

A special identification method was developped for bridges [4]. It is based on dynamic tests where the bridge is loaded by a periodic exciter. (An other possibility of loading would be an impact by a load or by a rocket motor, or a moving vehicle. However, the last types of loading are less convenient than an exciter because they excite more harmonics.)

The identification of a damage and of incorrect function of bearings is shown in Fig. 2 as an example. It represents a prestressed concrete highway bridge which was damaged by peeled off concrete. The excitation by a harmonic force provided the measured frequency $f_{exp} = 2{,}343$ Hz (Fig. 2d) that did not correspond to the theoretical calculations (Fig. 2b). It was discovered that the bearings were blocked after 20 years traffic. The new theoretical model gave the value 2,34 Hz (Fig. 2c) that is in good agreement with the measured value 2,343 Hz (Fig. 2d). Even the mode of natural vibration is similar.

Moreover, the experimental excited mode discovered the place of damage (peeled off concrete, Fig. 2a) where the amplitude was higher (+29%) than on opposite side of the bridge.

4. EFFECT OF DAMAGES

An other important question is the investigation of the deterioration of a bridge and of the location of a damage. This is possible using the repeated identification.

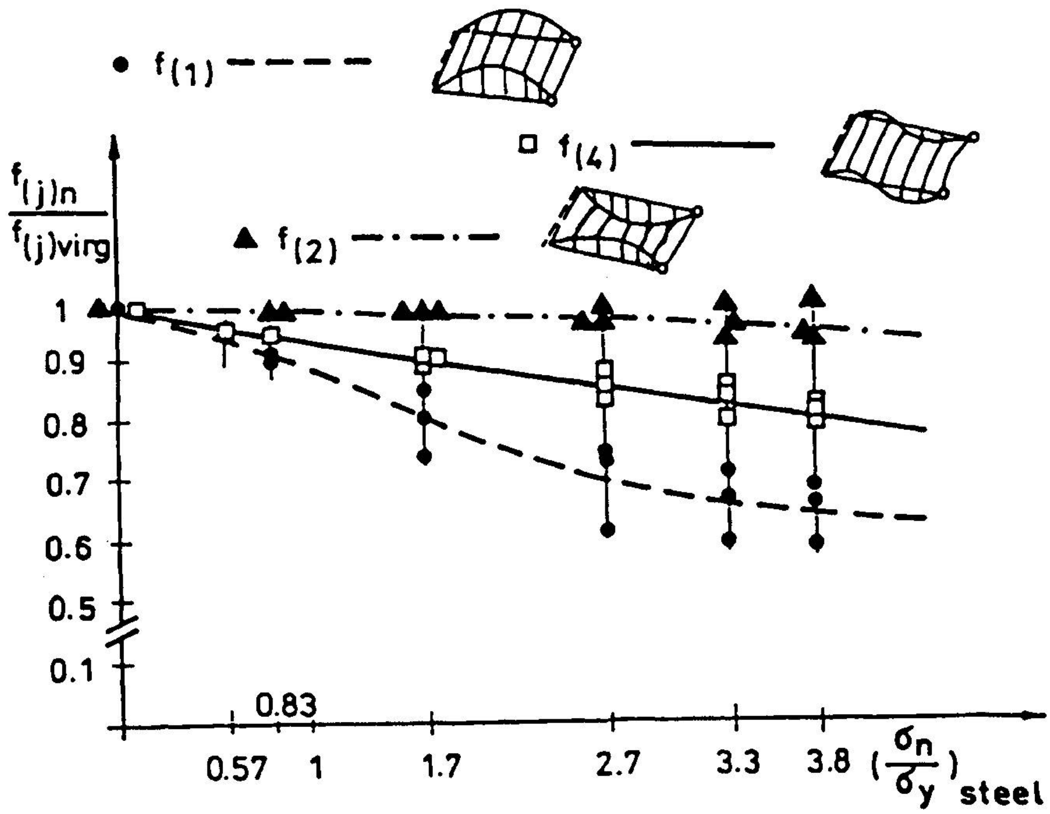


Fig. 3 Natural frequencies of 3 unloaded plates as a function of static loading :
$f_{(j)n}$ – j-th natural frequency after the n-th load step,
$f_{(j)virg}$ – j-th natural frequency before loading (in virginal state),
σ_n – real stress in steel bars after the n-th load step,
σ_y – yield stress of steel

As experiment, three rectangular concrete plates reinforced by a double net 6ø6 mm/m were produced; dimensions 1,5x2 m, thickness 50 mm, hinged supported along the short side and two pendulum bearings at the corners of the opposite side. The plates were loaded at their centres in steps by 1,25; 2,5; 4; 5 and 5,7 kN. The static load acted for 4 minutes on the plate and between every two loads the cracks in concrete and dynamic response of unloaded plate were measured. For dynamic testing an electrodynamic exciter was applied. The response was measured in 35 points.

It has shown (Fig. 3) that the repeated loading affects the cracks in concrete, natural frequencies and modes of natural vibration. The cracks diminish the natural frequencies, especially $f_{(1)}$ while the frequency $f_{(2)}$, corresponding to the torsion, was hardly affected. The diminishing in frequencies amounted to 30-40% for $f_{(1)}$, 0,5-7% for $f_{(2)}$, 17-23% for $f_{(3)}$ and 17-20% for $f_{(4)}$ after the fifth load 5,7 kN.

The values $(\sigma_n/\sigma_y)_{steel}$ = 0,57; 0,83; 1; 1,7; 2,7; 3,3 and 3,8 correspond to the applied static forces 0,86; 1,25 (maximum life load); 1,5; 2,5; 4; 5 and 5,7 kN, respectively in the Fig 3. The energy necessary for the excitation of the response diminishes with the increasing deterioration of plates. The sequence of this conclusion is the increasing dynamic yielding with increasing load.

5. CONCLUSIONS

Monitoring of stresses in bridges for a longer period presents valuable data necessary for the estimation of their fatigue life. It has appeared that both static and dynamic stress ranges and their distribution are very important.

The repeated monitoring could recognize the damages and their location in bridges. Of course, it means the repetition of experiments several times in intervals, say 10 years, under the same conditions including the identification of the original state before traffic (virginal state). A series of such tests may identify the damages and their location. Corresponding criteria for the changes in the natural frequencies and for deformations of modes of natural vibration should be developped in the future.

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